WLS Gasses for High-Pressure Xenon Detectors

Victor M. Gehman for Dave Nygren
LIDINE2013
May 30, 2013
Fermilab. Batavia, Il
High-Pressure Gas Detectors

- Good for $0\nu\beta\beta$ and for dark matter!
- Excellent energy resolution (critical for $0\nu\beta\beta$, can also lower threshold for dark matter)
- Track imaging for high-fidelity track topology (enhanced background rejection)
- Small charge to light fluctuations (more precisely defined signal and background regions)
- Can possibly extract nuclear recoil track direction (would be a game changer for dark matter!)
Detector Schematic

Asymmetric TPC with “Separated functions”

- Virtual Fiducial surface
- Transparent -HV cathode
- Electroluminescent plane
- Energy plane
- Field cage: teflon
- Energy & primary scintillation signals recorded here, with PMTs
- Operating pressure: 10 -15 bars
- EL signal created here
- Tracking performed here, with “SiPMT” array
- Field cage: teflon
- Electrons
- Ions

14 April 2013
APS Denver - David Nygren
Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.
A Recent Result!

A Recent Result!

Tracking Too!

Real track from $^{137}$Cs $\gamma$-ray – reconstructed with SiPMs

NEXT-DEMO  IFIC, Valencia
What’s the next step?

• Previous results were done with pure Xe (tracking plane had evaporated TPB)
• Track directionality would make a very strong case for direct detection of dark matter
• Most current experiments try for directionality by imaging the nuclear recoil track:
  • Very diffuse detectors (low target mass)
  • High energy threshold
  • Poor track image quality
A Different Approach!

- Use *columnar recombination* (CR) to extract track direction...
- Requires ionization electrons drift back through parent track:
  - Depends on angle between drift field and track direction
  - Other recombination types are independent of this angle
How to Maximize This Effect?

- Define “Columnarity,” \( C = \frac{R}{r_0} \)
- Represents the maximal difference in recombination from track angle

In 0.05 g/cm\(^3\) xenon gas:
- \( R \equiv \) Nuclear recoil track range \( \approx 2.1 \ \mu m \)
- \( r_0 \equiv \) Onsager radius \( \approx 70 \ \text{nm} \) (recombination distance)
- \( e \equiv \) electron charge, \( \varepsilon \equiv \) gas dielectric constant,
  \( E_e \equiv \) electron kinetic energy (usually taken as kT)
- \( C \approx 30 \) in this case (would like \( C > 10 \ldots \))
So What Do We Need?

• We have:
  • Short tracks (~70 nm)...  Don’t lose electrons!
  • Small signals...  Don’t waste electrons or photons!
  
• Lots of energy deposited form nuclear recoils goes into primary excitations, but...
  • excitations don’t contribute to the CR signal!
  • Use the Penning Effect: convert excitons to ions with a molecular additive so that these can contribute to CR too!

• Bonus: the same molecule can cool the electrons, thus increasing the recombination probability
But Wait, There’s More!

• Remember that we are detecting ionization electrons with electro-luminescence light, therefore...

• Poor photon collection efficiency means poor charge collection efficiency!!!

• We can achieve nearly 100% coverage if we cover the inside of the TPC with WLS plastic panels read out with PMTs (or APD’s, or SiPMs, etc.)

• But most WLS plastic panels are not very efficient in VUV–300 nm light is pretty close to optimal though.

• Must shift 173 nm photons to 300 nm photons in the gas!
But Wait, There’s More!

• Remember that we are detecting ionization electrons with electro-luminescence light, therefore...

• Poor photon collection efficiency means poor charge collection efficiency!!!

• We can achieve nearly 100% coverage if we cover the inside of the TPC with WLS plastic panels read out with PMTs (or APD’s, or SiPMs, etc.)

• But most WLS plastic panels are not very efficient in VUV–300 nm light is pretty close to optimal though.

• Must shift 173 nm photons to 300 nm photons in the gas!
Two Birds With One Stone

To extract the CR signal from a HPXe gas detector, we need two things:

- Penning additive to convert excitations into ionizations
- WLS that absorbs at 173 nm and fluoresces at $\approx 300$ nm

Provenance! Tri-methyl-amine (TMA) is a Penning gas known to fluoresce efficiently at 300 nm!

Also possible: Tri-ethyl-amine (TEA)
What Might This Look Like?

≈2 m
What Might This Look Like?
What Might This Look Like?
Shorter Term R&D

• The “TEA Pot”

• Measures basic response characteristics
  
  • Parallel-plate ionization chamber with optical sensing using 4 PMTs that look at the gap from the sides
  
  • Will measure both light and charge as functions of density, electric field, and fraction of TMA/TEA
Shorter Term R&D
Shorter Term R&D

OSPREY: “Opportunities for Superior Performance in Rare Event Yields”
Conclusions

• This is a really unusual way to get at dark matter directionality

• Each step is quite plausible, but there are several unknowns to be addressed:
  • Penning efficiency of TMA?
  • Fluorescence efficiency of TMA in recombination?
  • Rate of ionic charge exchange?
  • Cooling rate of electrons after ionization?

• Initial simulations and R&D is underway!